NexSat

Previewing NPOESS/VIIRS Imagery Capabilities

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The NexSat Web page offers an educational and operationally relevant preview to satellite imagery capabilities anticipated from NPOESS—tomorrow's National Polar-orbiting Environmental Satellite Program.

Weather is an uncontrollable factor impacting the federal budget of the United States both directly (e.g., through disaster management and unemployment costs) and indirectly (e.g., through resource shortages leading to increased prices) to the tune of billions of dollars annually. Through investment in improved satellite remote-sensing resources, we improve in turn our ability to observe and predict the phenomena responsible for these financial impacts. This knowledge places decision makers in a better position to take the most appropriate actions in avoiding or mitigating the consequences of weather. The National Polar-orbiting Operational Environmental Satellite System (NPOESS) consolidates the expertise and resources of the current National Oceanic and Atmospheric Administration (NOAA), National Aeronautics and Space Administration (NASA), and Department of Defense (DoD) environmental satellite programs to produce a substantially improved next-generation operational system. The program represents a substantial investment of taxpayer dollars toward the future safety, security, and economic prosperity of our nation.

During Operation Enduring Freedom (OEF) and Operation Iraqi Freedom (OIF), both operational and research-grade environmental satellites provided the DoD with access to near-real-time weather products (e.g., Miller et al. 2006) from the Moderate Resolution Imaging Spectroradiometer (MODIS; e.g., King et al. 1992) instruments flying aboard the Earth Observing System (EOS) *Terra* and *Aqua* satellites. The high spatial, spectral, and radiometric resolution attributes of MODIS offered a clear advantage in environmental characterization over contemporary

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operational platforms. Through coordination with the NPOESS Integrated Program Office (IPO), the Naval Research Laboratory (NRL) now demonstrates similar capabilities in the public domain via the "NexSat" Web page (www.nrlmry.navy.mil/NEXSAT.html/). Highlighting capabilities anticipated from the NPOESS Visible/Infrared Imager/Radiometer Suite (VIIRS), NexSat features a suite of value-added environmental products and physically based feature enhancements (e.g., detection of snow cover, low clouds, cirrus, convection, and dust) over the continental United States (CONUS). These NPOESS-like products are based on real-time and near-real-time satellite telemetries from VIIRS heritage/risk-reduction radiometers: *Terra*/*Aqua* MODIS, the NOAA Polar Orbiting Environmental Satellite System (POES) Advanced Very High Resolution Radiometer (AVHRR), and the Defense Meteorological Satellite Program (DMSP) Operational Linescan System (OLS). Auxiliary data from U.S. Navy global and mesoscale numerical weather prediction (NWP) model fields (e.g., Hogan et al. 1991, Hodur 1997) are also used in a subset of NexSat products.

The purpose of NexSat is to illustrate NPOESS/VIIRS sensor advances over contemporary operational capabilities in the ability to characterize and quantify, and in concert with NWP, predict future states of the environment. Communicating these capabilities in near-real-time and in a visually intuitive way broadens the audience of potential users. NexSat products have proven useful to television weather broadcasters and can be expected to benefit the transportation industry along with natural resource and disaster management agencies. This paper outlines the derivation, development, and implementation of the NexSat Webs. The sections to follow detail i) an overview of NPOESS/VIIRS and the attributes of its heritage observing systems, ii) the production system responsible for data ingesting, fusing, and near-real-time processing, iii) the design and functionality of the NexSat Web page, and iv) examples illustrating the scope of practical applications from this new online resource.

NPOESS/VIIRS OVERVIEW. In the coming decade, the launch of the first in a series of highly capable sun-synchronous operational environmental satellites will mark the official consolidation of the DMSP and POES operational satellite programs. The NPOESS constellation will entail three operational satellites with daytime equatorial crossings of 0930, 1330, and 1730 LT. The principal imagery device to operate aboard NPOESS is the VIIRS—a hybrid of several sensors currently aboard operational (DMSP OLS and POES AVHRR) and research satellites (NASA MODIS). As risk reduction for NPOESS, the NPOESS Preparatory Project (NPP; to launch in approximately 2008) will carry a number of the NPOESS prototype instruments, including VIIRS.

VIIRS will feature a total of 22 spectral bands: 9 across the visible/near-infrared spectrum (0.4–0.9 μm), 8 in the short/midwave infrared (1–4 μm), 4 in the longwave infrared (8–12 μm), and a low-light visible band (0.7 μm). VIIRS is an ambitious sensor from an operational standpoint. It is tasked to address (either independently or in concert with other NPOESS sensors) nearly half of the NPOESS environmental data records (EDRs) pertaining to the atmosphere (e.g., clouds, smoke, volcanic ash), lithosphere (e.g., fire detection, high-resolution imagery, vegetation), biosphere (e.g., land vegetation and ocean color), cryosphere (e.g., polar sea ice), and hydrosphere (e.g., sea surface temperature, ocean color). Table 1 compares the proposed forthcoming VIIRS instrument against contemporary OLS, AVHRR, and MODIS sensors. Also shown are channels available from the current NOAA Geostationary Operational Environmental Satellite (GOES) imagers, sensors that are included on NexSat for the purpose of providing a dynamic context to the high-detail "snapshot" depictions offered from the various polar-orbiting platforms. These observing systems are described in more detail in the following section.

VIIRS includes 5 high-spatial-resolution (roughly 370 m at nadir and 800 m at edge of scan) imager channels similar to POES and 16 moderate-resolution (roughly 740 m at nadir and 1.6 km at edge of scan) channels (including many from MODIS). The nighttime visible band (Lee et al. 2006) is similar and in many ways superior (having higher signal-to-noise ratio, higher spatial resolution, higher radiometric resolution, calibrated, and adjustable gain settings) to the DMSP OLS version. With these improvements over the current operational programs, VIIRS will be in a much better position to meet increasingly stringent user requirements on environmental parameter fidelity.

The primary shortcomings of the initial VIIRS design are its lack of an infrared water vapor (e.g., 6.7 μm) band and its low 11.0-μm saturation temperature (at 343 K). The water vapor channel has demonstrated value for polar wind vector estimates via feature-tracking techniques (e.g., Key et al. 2002; feasible due to the high temporal sampling frequency of polar-orbiting satellites at high latitudes). The 11.0-μm channel would require a higher saturation

Table 1. Spectral bands (μm; central wavelength) of VIIRS as compared with OLS, AVHRR, and MODIS sensors. Instrument band indices provided in parentheses where applicable. Also shown are *GOES-10/-12* bands provided on NexSat. Note that the *GOES-12* 13.3-μm band is indexed as "6" to avoid confusion with contemporary *GOES* (*-9/-10/-11*) imagers.

NexSat sensor suite channels (μm) and channel indices (parentheses)					
VIIRS	OLS	AVHRR	MODIS	*GOES-10*	*GOES-12*
0.412 (M1)	—	—	0.412 (8)	—	—
0.445 M2)	—	—	0.442 (9)	—	—
—	—	—	0.465 (3)	—	—
0.488 (M3)	—	—	0.486 (10)	—	—
—	—	—	0.529 (11)	—	—
—	—	—	0.547 (12)	—	—
0.555 (M4)	—	—	0.553 (4)	—	—
0.640 (I1)	—	0.63 (1)	0.646 (1)	0.65 (1)	0.65 (1)
—	—	—	0.665 (13)	—	—
0.672 (M5)	—	—	0.677 (14)	—	—
0.7 day/night	0.7 day/night	—	—	—	—
0.746 (M6)	0.75	—	0.746 (15)	—	—
			0.856 (2)	—	—
0.865 (I2, M7)	—	0.863 (2)	0.866 (16)	—	—
—	—	—	0.904 (17)	—	—
—	—	—	0.935 (18)	—	—
—	—	—	0.936 (19)	—	—
1.24 (M8)	—	—	1.24 (5)	—	—
1.378 (M9)	—	—	1.38 (26)	—	—
1.61 (I3, M10)	—	1.61 (3A)	1.69 (6)	—	—
2.25 (M11)	—	—	2.11 (7)	—	—
3.70 (M4)	—	—	—	—	—
3.74 (I4)	—	3.74 (3B)	3.79 (20)	—	—
—	—	—	3.99 (21)	3.9 (2)	3.9 (2)
—	—	—	3.97 (22)	—	—
4.05 (M13)	—	—	4.06 (23)	—	—
—	—	—	6.76 (27)	6.7 (3)	6.7 (3)
—	—	—	7.33 (28)	—	—
8.55 (M14)	—	—	8.52 (29)	—	—
—	—	—	9.72 (30)	—	—
10.763 (M15)	—	10.8 (4)	11.0 (31)	10.7 (4)	10.7 (4)
11.45 (I5)	11.6	12.0 (5)	12.0 (32)	12.0 (5)	—
12.013 (M16)	—	—	13.4 (33)	—	13.3 (6)
—	—	—	13.7 (34)	—	—
—	—	—	13.9 (35)	—	—
—	—	—	14.2 (36)	—	—

temperature in order to quantify fire temperatures and subsequently parameterize smoke emission [e.g., as used by the U.S. Forest Service (USFS) and U.S. Geological Survey (USGS) to monitor fires and land-use changes, the Environmental Protection Agency (EPA) or air quality predictions, and the Department of Defense (DoD) for path visibility estimates]. However, a protocol for evolving user requirements during the NPOESS program may allow for accommodation of these needs on follow-on VIIRS sensors [i.e., preplanned products improvements (P^3I) for sensors scheduled to fly aboard the follow-on members of this constellation].

The data acquisition (ground segment) of NPOESS will involve a so-called Safety Net system comprising multiple globally distributed unmanned downlink stations connected through public fiber optic communication lines to four central processing facilities. The Safety Net will enable receipt of 75% of global VIIRS within 15 minutes of observation and the remainder within 30 minutes—timeliness unattainable by contemporary operational polar-orbiter systems. For comparison, the Near-Real-Time Processing Effort (NRTPE; Haggerty et al. 2003, Miller et al. 2006) provides latencies on the order of 2 h for global MODIS data.

SATELLITE OBSERVING SYSTEM BUILDING BLOCKS. In the years leading up to the launch of NPP, NexSat will rely on the suite of heritage sensors mentioned above to simulate the capabilities anticipated from VIIRS. The following subsections describe the salient features of these contemporary resources.

DMSP OLS. The Defense Meteorological Satellite Program was developed by the U.S. Air Force originally for tactical meteorological applications. The members of the DMSP constellation follow sun-synchronous (always crossing the equator at the same local time) orbits at 830-km altitude with 101-min. periods. At the time of this writing, two primary (*F13* and *F16*) and two secondary (*F14* and *F15*) DMSP satellites provide operational global data (two additional satellites, *F8* and *F12,* operate in test and tactical modes exclusively). With the exception of *F15,* the DMSP satellite orbits are situated near the day/night terminator for "first light" observations. The OLS includes two telescopes for the visible (0.7 μm, uncalibrated) and infrared window (11 μm, 8-bit linear calibration across 190–310 K) bands, and a high-amplifying photomultiplier tube (PMT) for the broad nighttime visible band (designed for cloud imaging under moonlit conditions) across its 3000-km swath. The nighttime visible band provides the only heritage to the day/night band (DNB) included on VIIRS.

An important mechanical feature of the OLS is its implementation of 1) a pendulum-motion (i.e., slowing at scan edge) "whisk broom" scanning strategy, 2) constant sample rate, and 3) decreasing detector field of view (FOV) with increasing scan angle (see Elvidge et al. 1997). The combination achieves equidistant pixels and a near-constant detector footprint upon the Earth's surface in the cross-track direction with minimal degradation of spatial resolution and signal-to-noise ratio at the edge of the swath. This is in contrast to AVHRR and MODIS, whose constant FOVs and scan rates result in significantly coarser spatial resolution at high scan angles (e.g., VIIRS 0.76-km imager bands will offer roughly 5 times the cross-track pixel resolution at scan edge). NRL receives global DMSP OLS smooth (2.7-km resolution) format data from the Air Force Weather Agency (AFWA) via the Fleet Numerical Meteorology and Oceanography Center (FNMOC). Owing to current restrictions mandated on the public release of these data, NexSat adheres to a 3-h embargo policy for all its OLS applications.

NOAA POES AVHRR. The NOAA POES series features a constellation of sun-synchronous satellites having orbital altitudes of 833 km and periods of 102 min. Currently, the primary satellites are *NOAA-16* (afternoon pass) and *NOAA-17* (morning pass), with *NOAA-15* as backup for *NOAA-17.* The primary instrument aboard contemporary POES platforms, the AVHRR, provides six spectral bands: visible (band 1; 0.65 μm), near infrared (band 2; 0.86 μm), shortwave infrared (band 3A; 1.6 μm and band 3B; 3.7 μm), and thermal infrared (band 4; 11.0 μm and band 5; 12.0 μm). To avoid thermal contamination in band 3B during the day *NOAA-17* switches between band 3A (daytime) and 3B (nighttime). *NOAA-16* maintains band 3B during both day and night.

The superior spectral capabilities of AVHRR as compared to OLS enable additional hydrological, oceanographic, and meteorological applications, including surface characterization, improved snow cover detection, cloud property determination, and fire detection. AVHRR does not contain a nighttime visible band, and due to its constant scan rate and fixed detector aperture lacks the higher swath-edge resolution and pixel spacing demonstrated by the OLS. NRL receives CONUS-domain AVHRR through a combination of local and remotely captured high-resolution picture transmission (HRPT; 1.1-km pixels at center of swath) reception. Global data are provided via subscriptions to the NOAA Satellite Active Archive (SAA). Latencies on the AVHRR data range from only minutes for HRPT to 2.0–2.5 h for the SAA datasets.

NASA MODIS. MODIS instruments feature 36 narrow bands across the optical spectrum between 0.4 and 14.4 μm. Spatial resolution among these bands varies from 1 km in the thermal infrared (bands 8–36) to 500 m in the blue/green visible and shortwave infrared (channels 3–7) and 250 m in the red visible and near infrared (bands 1–2, respectively). MODIS is carried aboard the sun-synchronous EOS *Terra* and *Aqua* satellites (with 705-km orbit altitudes and 99-minute periods). *Terra* (launched December 1999) provides a daytime equatorial crossing (1030 LT) on a northeast-to-southwest descending node, and *Aqua* (launched May 2002) crosses the equator roughly 3 h later (1300 LT) on a southeast-to-northwest ascending node. This two-satellite constellation therefore suffers a 7-h gap on average between daytime and nighttime passes near the equator. This sampling problem will be avoided in the NPOESS era by implementing a three-satellite constellation with local equatorial crossing times separated by 4 h, thereby providing roughly 4-h temporal resolution at the equator with sample frequency improving with increasing latitude.

NRL receives global *Terra* and *Aqua* MODIS data in near-real-time (typically around 2 h after observation) via the NRTPE, a coordination with NOAA, NASA, the U.S. Navy, and the U.S. Air Force. All available spatial resolutions of level-1B (calibrated radiometric measurements) data are received along with a subset of level 2 (environmental data records) that includes aerosol and cloud properties. The NRTPE allows NRL to host a suite of MODIS-derived products meeting the timeliness requirements for utility in military applications. In the context of NexSat, the NRTPE facilitates the incorporation of multiple streaming ancillary datasets [e.g., NWP fields and METAR (translated roughly from French as "aviation routine weather report") observations] in the production system discussed further along, as well as expanding product relevance to a wider audience of users.

Geostationary satellite datasets. To provide higher temporal resolution and fill in the time gaps resulting from the infrequent and irregularly spaced sampling of the CONUS domain by the *Terra*/*Aqua*/DMSP/POES polar-orbiting constellation, observations from the NOAA GOES supplement NexSat. Available to NRL in real time currently via the *GOES-10* (135°W) and *GOES-12* (75°W) rebroadcast, GOES provides a dynamical context to the AVHRR/OLS/MODIS "snapshots," and a standard by which the value-addedness of the various NexSat products may be assessed. It also enables space–time matching to DMSP observations for augmentation of infrared-only applications through use of the OLS nighttime visible channel (e.g., simulating the VIIRS observing system).

The ensemble NexSat observing system. Leveraging the full complement of VIIRS heritage sensors, the overarching goal of NexSat is to illustrate via a) intersensor comparisons, b) multisensor and sensor/model-fusion products, and c) stand-alone sensor demonstrations (where applicable), the forthcoming capabilities of the next-generation system. For example, improvements due to increased spatial resolution can be demonstrated with MODIS 250-m visible data (e.g., subsampled to VIIRS 370-m pixels) versus 1.1-km AVHRR imagery. At swath edge, OLS may be compared against AVHRR or MODIS to demonstrate additional spatial resolution improvements of VIIRS over AVHRR. Spectrally, MODIS provides many opportunities to demonstrate improved environmental characterization beyond OLS/AVHRR capabilities.

Multisensor products can be addressed on spatially and temporally matched data. In addition to matches between the polar orbiters with coregistered geostationary data, potential matches currently exist between the following pairs: *NOAA-15* [1826 LT ascending node (LTAN)] with *F-13* (1828 LTAN), *NOAA-17* (2223 LTAN) with *Terra* (2230 LTAN) or *F-15* (2112 LTAN), and *NOAA-16* (1420 LTAN) with *Aqua* (1330 LTAN). The likelihood of finding better spatial and temporal matches among the various polar-orbiting sensors increases toward polar latitudes. The high temporal refresh of GOES affords additional opportunities for sensor-to-sensor comparisons, based on channels shared among GOES/AVHRR/OLS and the additional spectral information available from MODIS. Here, coregistered data over domains where sensor observations match within a specified time criteria are selected for analysis.

VIIRS simulations and product comparisons are inherently limited by the restrictions and compatibilities of the independent heritage sensor datasets available to NexSat. In such cases where a full end-to-end simulation is impossible, NexSat emphasizes instead the product concepts that will become a reality in the VIIRS era. For example, the scope of applications pertaining to the VIIRS nighttime visible band (e.g., Lee et al. 2006) is limited by the fact that the OLS equivalent band is uncalibrated, 6-bit data, whereas the equivalent band on VIIRS will offer calibrated data at significantly higher radiometric resolution (14 bit). As such, NexSat applications emphasize the detection capabilities of the nighttime visible band (examples below) as opposed to the potential quantitative applications from calibrated data.

THE AUTOMATED PROCESSING SYSTEM.

Processing of the large (> 50 GB day^{-1}) CONUS ensemble satellite dataset is tasked to a multiprocessor cluster running a portable batch system (PBS) queuing architecture with an onboard 300-GB redundant array of independent disks. The system is essentially a collection of Linux machines (each having dual 2.8-GHz processors with 4-GB memory cards) operating serially and tasked by a server according to its current load. To minimize input/output (I/O) delays and network file system (NFS) mount points, satellite and numerical model fields are cached to local disks. Mirrored system disks, dual power supplies, a backup generator, and stand-alone configuration provide additional fail-safes and system stability. The generic system is configured to readily accept additional processing nodes if computational demands increase.

A series of preprocessing steps (quality checks, format/units conversions, and corrections) initiates upon first receipt of new data in preparation for calls to the science algorithms. Each science algorithm, wrapped within a generic driver script for rapid application to new domains, is called automatically upon completion of data preprocessing. To handle an arbitrary list of coverage boxes, wrapper scripts interrogate a list of configuration files containing all information relevant to a given coverage sector (position, pixel size, map projection, coastline/grid/text annotation specification, product-dependent variables, destination directory, etc.). Value-added products are distributed to terabyte-capacity network area storage (NAS) systems (allowing for large online archives). Terascan (SeaSpace Corporation) and the Interactive Data Language (IDL; Research Systems Incorporated) are used as the primary visualization packages.

THE NexSat BROWSER.

Miller et al. (2006) describe the Satellite Focus Web page, developed by NRL and hosted operationally on secure Internet by FNMOC. Conceived during the post–September 11th military mobilization leading up to OEF, Satellite Focus aimed to consolidate all available-near-real-time satellite telemetries within a common framework. The resource facilitated rapid information gathering in a time-critical decision-making environment. This section draws parallels to the form and functionality of Satellite Focus in describing the content and utility of NexSat.

Form. NexSat draws upon constructs established for Satellite Focus and the Tropical Cyclone Web page (Hawkins et al. 2001). It employs a telescoping directory structure for storage of progressively higher spatial resolution products (toward increasing spatial resolution, e.g., from coarse-scale "regions" to finescale "sectors"). Definitions pertaining to the scale of these domains/regions/sectors are left general, since these parameters are relative to the sensors in question (e.g., 250-m visible data, for MODIS is fine compared to 1-km GOES, but coarse compared to 30-m Landsat Thematic Mapper imagery). Sectors may remain fixed on a particular area (e.g., southern California in the Western Region), or come into and out of existence dynamically according to current events (e.g., in fall 2004, a "Mt. St. Helens" sector was opened in the Western Region of NexSat to provide real-time coverage over the stirring volcano, and a sector along the Florida coastline was initiated in the days prior to the landfall of Hurricane Frances). The current production system allows for population of new areas of interest with a full complement of available satellite products in a matter of minutes, for example, to capture a developing event. Within each sector of the NexSat architecture resides a suite of area-specific products (e.g., snow cover products are not produced for a Gulf of Mexico ocean-coverage box, and 250-m resolution imagery products are confined to the smallest sectors for image size considerations). Environmental applications are ranked above the contributing satellite sensors in the storage hierarchy, since various sensors may be capable of creating the same product at various levels of detail and accuracy (side-by-side comparisons are a key element of NexSat). This convention is another carryover from Satellite Focus, where operational users in general are concerned more with the information than its particular source.

Functionality. NexSat is a graphical user interface accessible by Internet browsers. Operation of the Web page is largely self-explanatory, with drop-down menus and highlighted buttons controlling area, product, and sensor specification. The screen capture shown in Fig. 1 illustrates the basic layout, with area navigation buttons at the top frame, product selection buttons in the left frame, and the most recent satellite imagery for the selected product displayed in the lower-right frame. Satellite products are also viewable as a collection of the most recent quick-look thumbnail images ("Thumbs"), whereby the user may scan for scenes/times of interest and proceed to select higher-quality versions. The currently selected product type is preserved when a user selects a new geographic coverage area, and image times are preserved (or matched as closely as possible) when switching between various imagery products. User-configurable interfaces for animation and interrogation of the online archive (typically spanning from several days for GOES to several weeks for the less frequently updated polar-orbiter datasets) facilitate exploration of the page. In the interest of operational users, all product buttons are color coded (green < 12 h, yellow < 24 h, red ≥ 24 h) according to the most recent observations available. Users may toggle between temporally matched products from individual satellite passes or multiple-pass composites (valid for larger areas), and view satellite-pass prediction coverage maps.

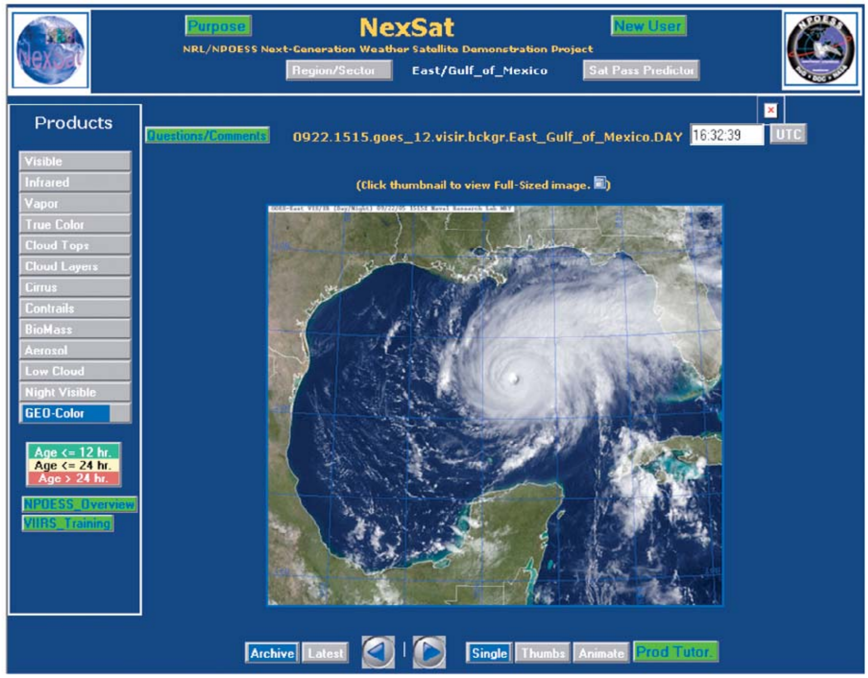

Fig. 1. Example screen capture of the NexSat Web page. Sector navigation, product selection, and product display options are located at top, left, and bottom, respectively.

Training. Training is a key component to communicating NexSat's message of NPOESS-era capabilities while educating new users (especially the general public) who are unfamiliar with the interpretation, utility, and any particular caveats associated with the products. Visitors are directed toward overview ("Purpose") and page-usage ("New User") tutorial buttons located at the top of the page. Overviews of the NPOESS program ("NPOESS Overview") and the VIIRS sensor ("VIIRS Training") are provided beneath the products selection list. Through collaboration with the Cooperative Program for Operation Meteorology, Education, and Training (COMET; www.comet.ucar.edu/), NexSat features "Webcasts" (online slide shows with animation and narration) for several of these modules. Specific training modules for each of the NexSat products ("Prod. Tutor"), located beneath the imagery display area, provide motivation, method, and interpretation, and linkage to NPOESS-era capabilities. These materials are presented at a high level, and users wishing to explore the topics in greater detail are provided additional links to online materials (e.g., topical Web sites on papers).

SELECTED EXAMPLES. NexSat leverages applications developed originally by NRL researchers for mission support during OEF and OIF. Conveniently, most of the meteorological phenomena characterizing southwest Asia bear direct relevance to the CONUS domain. For example, the complicated cloud/snow scenarios over Afghanistan draw similarities to the Rockies and the Sierra Nevada ranges. Low clouds and fog common over the northern Arabian Sea translate to the semipersistent marine stratocumulus cloud decks of the eastern Pacific subsidence zone. Dust storms frequent to the Middle East also occur intermittently across the arid southwestern desert basins of the United States. Deep convection, similar to orographically forced storms near Pakistan and the United Arab Emirates, occur commonly over the central and southern United States throughout the summertime months. The examples to follow illustrate the the wide scope of useful applications included on NexSat. These products are based on satellite research and development programs ongoing at NRL Monterey.

Coregistered regional products. Figure 2 depicts the CONUS Overview domain defined by NexSat with true color composite, normalized difference vegetation index (NDVI), convective cloud-top heights, nighttime low clouds, nighttime light detection, and cirrus detection (e.g., Turk and Miller 2005). The domain extends outward 10°–15° in all directions from the U.S. borders to capture approaching weather

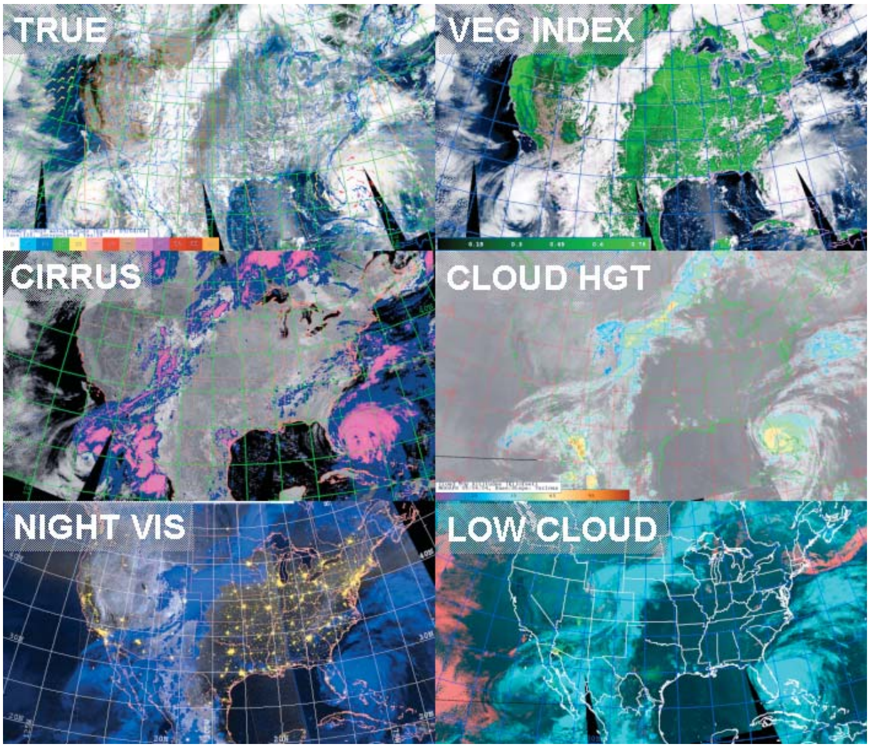

Fig. 2. The NexSat CONUS Overview domain with example coregistered products. Clockwise from upper left: true color with surface winds overlay, vegetation index (green), convective cloud-top heights (in color), low clouds (red) at night, nighttime lights (yellow), and cirrus detection [optically thin (blue), optically thick (magenta)].

systems. Although depicting high-spatial-resolution sensor advantages at these scales is not possible, such "big picture" views are useful for gaining a synoptic context on the current meteorological situation. When shown as composite imagery (e.g., the stitching together of multiple MODIS overpasses), they provide a glimpse of future GOES-R capabilities from the Advanced Baseline Imager (e.g., Schmit et al. 2005), to launch in 2012. From this vantage point, a user may key-in on the tropical systems over Florida or Baja California, the convective clouds over the Rocky Mountains deserts, or the low cloud decks over the Pacific Ocean and northeast coast. In each case, the user has the option to then zoom in to the areas of interest simply by selecting the most appropriate region/sector combination via the top-frame navigation button. These smaller sectors take advantage of the higher spatial resolution provided by the polar-orbiting observing systems.

High-resolution city zoom imagery. At the other extreme of spatial scale, NexSat features high-resolution MODIS (250-m pixel size at nadir) true-color products over selected major cities throughout the CONUS. Atmospheric corrections are applied to the red, green, and blue bands of MODIS to remove molecular scatter and improve image quality near scan edge. Figure 3 shows examples of some of these products centered over selected U.S. cities. The motivation for city zooms was to demonstrate spatial resolution capabilities on par with NPOESS/VIIRS (roughly 370 m across the entire swath) while capturing the interest of the general public by providing users with daily views of their local weather conditions.

Dust over the desert southwest. The "significant dust enhancement" (Miller 2003) was originally developed for applications over the Middle East (Miller et al. 2006) but is readily ported to the NexSat CONUS domain. Applied to MODIS and based on multiple channels across the optical spectrum, the enhancement exploits several optical properties of dust to distinguish it from other components (e.g., bright desert backgrounds) of the scene at significantly reduced ambiguity. A digital mask of dust coverage is then available for incorporation within other applications.

The southwestern desert regions of the CONUS occasionally produce impressive outbreaks of dust that are reminiscent of those observed common to the Middle East. While most dust storms over the CONUS originate from thunderstorm outflows (called "Haboobs" in the Middle East) and are often obscured on MODIS images by overlying cirrus anvils, synoptic-scale forcing (e.g., strong pre- and postfrontal winds) will on occasion lift substantial dust where the soil conditions permit. Figure 4 illustrates a synoptically forced dust event that occurred in the spring of 2004 over southwestern Nevada. The diffuse tan region observed in the upper (true color) panel is revealed to be a substantial area of significant dust (shown as pink in this enhancement, corresponding to visible optical thickness greater than about ~0.5) propagating southward along the California border. NPOESS/VIIRS will

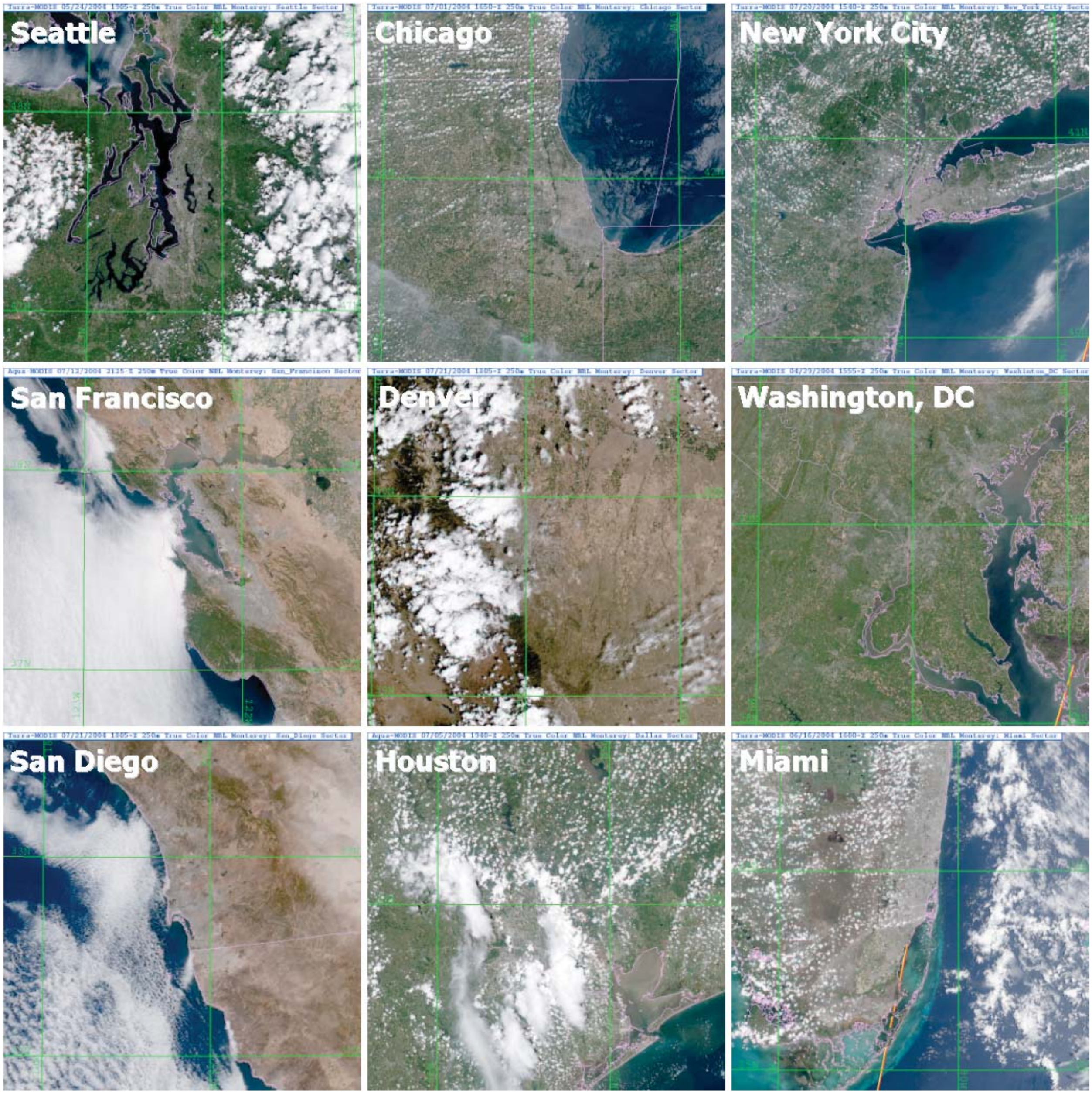

Fig. 3. Examples of MODIS 250-m resolution "City Zoom" true-color imagery for selected CONUS cities. The dimension of each panel is roughly 250 km on a side.

supply the requisite bands to implement this technique globally, and the late afternoon (1730 LT) satellite pass will be especially useful in tracking events tied strongly to the diurnal heating cycle.

Southern California wildfires. Kaufman et al. (1998) and Prins et al. (1998, 2001) demonstrate the value of the 4.0-μm band (available upon MODIS, GOES, and AVHRR) for detection and characterization of fires and hot spots. Owing to the highly nonlinear response of Planck blackbody radiation as a function of temperature, the 4.0-μm atmospheric window offers exceedingly higher sensitivity to hot sources (even when present only at subpixel scales) compared to the IR atmospheric window situated near 11.0 μm. The nighttime visible channel on the OLS provides an alternative detection method via subpixel light emissions from active fires. This adds a level of discrimination not directly measured by the heat-signature techniques, and provides an example of the improvements anticipated by VIIRS, which will contain all requisite bands.

In October 2003, wildfires fueled by years of drought and strong Santa Ana winds raged throughout southern California. Figure 5 depicts a scene of chaos as observed by MODIS, with fires detected by the algorithm highlighted in red. The fire lines are defined clearly, even through heavy smoke, and correspond closely with surface depictions. NPOESS/VIIRS will provide both detection methods mentioned above on the same platform and at higher spatial resolution than contemporary platforms. In addition, the day/night band upon VIIRS will assist in delineation of hot spots and actively burning zones.

Snow over the Midwest. Discriminating between cloud and snow cover over complex terrain with visible (both are bright) and infrared (can have similar temperatures) imagery is extremely challenging. Even the shortwave infrared channels (e.g., 1.6 and 3.9 μm), which provide improved discrimination of snow from liquid clouds due to enhanced snow absorption, suffer ambiguity with certain forms of cirrus. Miller et al. (2005) discuss multispectral techniques, combining the bands mentioned above with additional bands available on MODIS but not on AVHRR to improve discrimination, that yield improved delineation of cloud and snow.

An example of this technique is shown in Fig. 6 for a complex cloud/snow scene over the Midwestern United States. The visible image in the left panel of this example provides little insight on the snow distribution. In the right panel, the snow/cloud enhancement reveals the various components of the scene, including difficult to discern low clouds over snow. The 1.38-μm near-infrared vapor channel on MODIS enables discrimination between cirrus clouds (pink/magenta) and lower-tropospheric clouds, giving some indication of regions where multilayered clouds exist. The cloud/snow product will be highlighted during the winter months throughout the CONUS upon NexSat. The improved detection of snow cover from VIIRS (with similar capabilities to MODIS, in addition to the day/night band for detecting snow cover at night) will provide improved snow depiction over POES for use by resource managers, search and rescue, the DoD, and climate research.

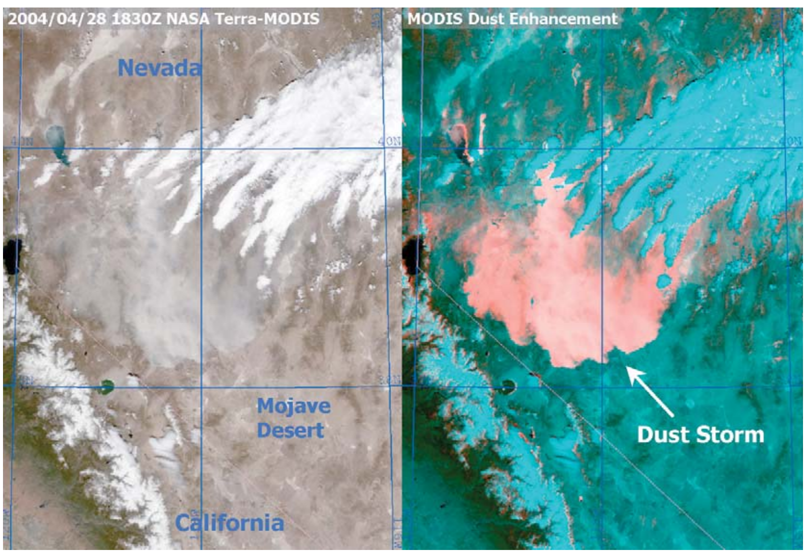

FIG. 4. (left) True-color and (right) dust-enhanced imagery of a large dust plume (pink) over the Great Basin and Mohave Deserts of southern Nevada on 28 Apr 2004. Latitude–longitude grid spacing is 2°.

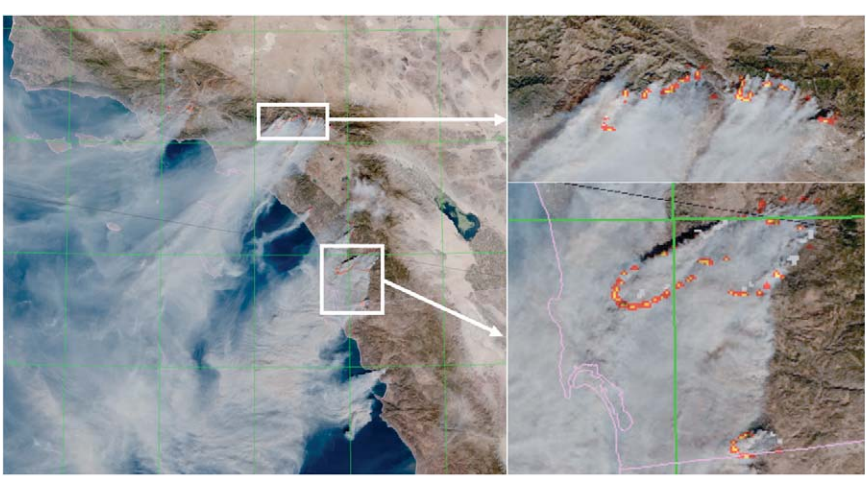

FIG. 5. MODIS fire/hot-spot overlay (red) depicts active fire lines from the southern California wildland fires on 26 Oct 2003. Latitude–longitude grid spacing is 1°.

Nighttime low-light applications. Low clouds and fog pose serious problems to aviation in terms of visibility impairment for landing aircraft and obscuration of low-altitude flight hazards. The main challenge to satellite detection of low clouds at night stems from the similar temperatures shared by clouds and the surrounding cloud-free land and ocean surfaces. Conventional techniques for low cloud detection at night include the 11.0–4.0-μm brightness temperature difference, which takes advantage of cloud-enhanced scattering at 4.0 μm (e.g., Kidder et al. 1998, Lee and Miller 2003) although the technique fails for clouds with large characteristic cloud-top drop sizes (less available cloud condensation nuclei, e.g., in maritime air masses). Under moonlit conditions, the VIIRS DNB will provide similar low cloud detection (upper panels of Fig. 7) with improved detection of pristine airmass clouds.

The heavy rain, hail, turbulence, microbursts, and lightning often associated with deep convection also pose high risk to aviation. Here, VIIRS DNB imagery will provide some indication of electrically active storms through its ability to detect the cloud-top flicker from lightning strikes. The lower panels of Fig. 7 demonstrate the nighttime visible band's ability to identify an embedded convective line as validated through National Lightning Detection Network (Vaisala)

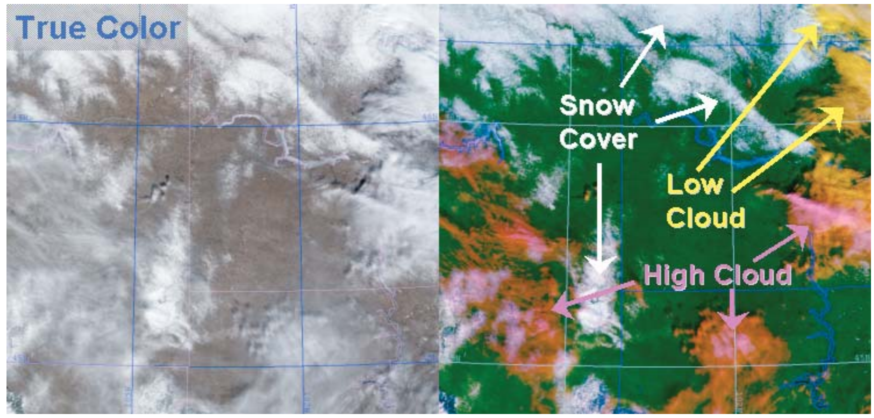

Fig. 6. (left) *Terra* MODIS true-color imagery for a complicated scene over the Midwestern United States at 1745 UTC 15 February 2002. (right) Simple cloud/snow enhancements leveraging multispectral MODIS observations readily discriminate snow (white), low clouds (yellow), and high clouds (orange/magenta). Dimension of region is 600 km on a side.

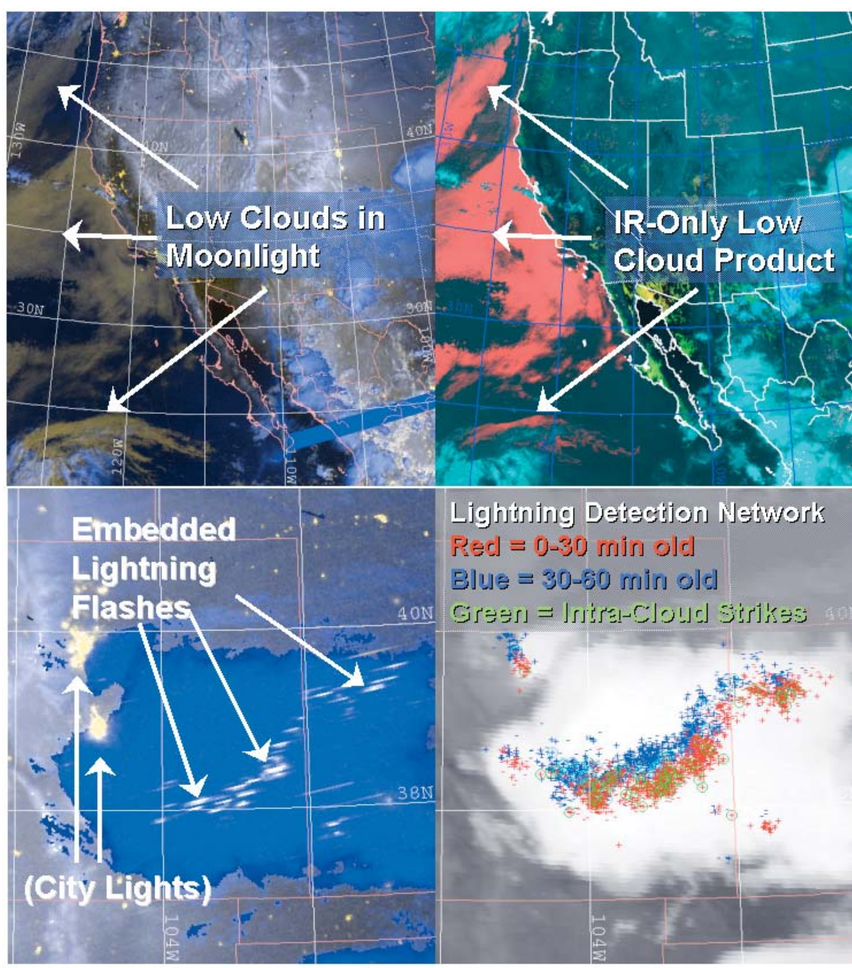

Fig. 7. (top left) Nighttime visible band enhancement (low clouds depicted in yellow, and high clouds depicted in blue) compared with (top right) infrared-only low cloud cover estimates (low clouds in red, high clouds in cyan) for 29 Aug 2004 at 0500 UTC over the western United States. (bottom left) Lightning flashes over eastern Colorado from 0310 UTC 11 Aug 2004 as detected by the OLS (lightning strikes appear as white streaks atop the blue convective clouds) with (bottom right) placement of the embedded convective line confirmed by National Lightning Detection Network data. City light sources are present in both OLS examples, appearing as discrete or linear patches of bright yellow.

data that would otherwise have been missed by conventional infrared observations. Because VIIRS is a scanning device, only the serendipitous crossing of a storm during a flash cycle will register a signal (with the likelihood increasing with storm flash rate). As such, this kind of product is more useful in determining where lightning is, rather than where it is not.

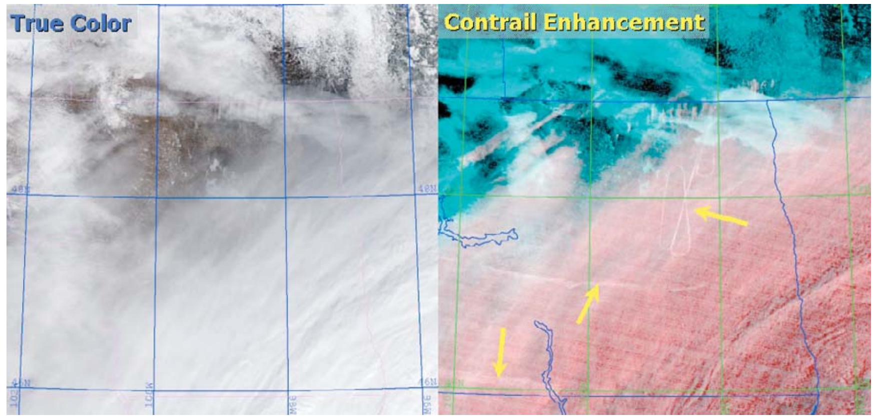

Fig. 8. (left) *Terra* MODIS true-color imagery and (right) the aircraft contrail enhancement revealing numerous aircraft tracks in the proximity of a cirrus shield over North Dakota at 1735 UTC 14 Mar 2002. Domain of region is 460 km on a side.

Aircraft contrails. Contrails form when warm, moist jet exhaust mixes with the cold upper-troposphere environment. Depending on the upper-tropospheric humidity (UTH), contrails may either dissipate rapidly or persist and spread over time (forming extensive cirrus shields). In the latter case these anthropogenically forced cirrus impact the radiative profile by reflecting sunlight and absorbing and reemitting terrestrial radiation, effectively reducing the diurnal range of surface temperature (Travis et al. 2002). In examining 25 years of satellite data under the assumptions of constant UTH and long-term trends in cirrus coverage being due entirely to aircraft activity (i.e., accounting for spread in favorable environments), Minnis et al. (2004) find that contrail formation can potentially account for nearly all of the observed warming over the period. To the DoD, they are of interest from the standpoints of surveillance and avoiding detection.

Several papers (e.g., Lee 1989; Weiss et al. 1998) illustrate contrail detection from space based on the "split window" 11.0–12.0-μm brightness temperature difference. The detection is based on stronger absorption by ice crystals comprising the contrail at 12.0 μm, leading to a depressed brightness temperature with respect to 11.0-μm measurements. Strabala et al. (1994) introduce a "trispectral" technique based on the split-window channels together with a third atmospheric window channel situated at 8.5 μm to enable the decoupling of liquid and ice-phase clouds. Although absorption by clouds increases monotonically from 8.5 to 12 μm, the rates of increase between liquid and ice phases are nonlinear and different enough such that ratios taken between the three measurements result in considerable decoupling. The NexSat contrail detection and enhancement method combines split-window contrail detection techniques with trispectral phase decoupling information. Figure 8 depicts ice-phase clouds as red, liquid clouds as cyan, and contrails as pink/white linear features. Contrails are also observed outside of cirrus shields whenever ambient upper-tropospheric moisture supports their initial formation, persistence, and growth. The high spatial and spectral resolution of VIIRS will provide improved detection capabilities for finescale (e.g., recently created) contrails.

PRACTICAL USES OF NexSat. The near-real-time production of NexSat value-added products opens the possibility for numerous operational uses. The transportation industry, including aviation, maritime, and commercial vehicle drivers, benefits from real-time depiction of both strong storms (e.g., convective cloud heights) and regions of developing fog (e.g., nighttime low-cloud product). Additional potential users include natural resource and disaster management agencies [e.g., Federal Emergency Management Agency (FEMA)], the EPA, the U.S. Border Patrol and the U.S. Coast Guard (e.g., supporting unmanned surveillance aircraft along the nation's borders and coastal waters). During the 2005 hurricane season, NexSat provided timely coverage of Hurricanes Katrina and Rita as they traversed the Gulf of Mexico. True-color imagery was incorporated into several television airings over this period, and the nighttime lights application monitored the power outages in the New Orleans, Louisiana, area. Over 300,000 accesses to the Web page were recorded on the day Katrina made landfall.

Many practical weather forecasting applications require high temporal resolution, and as such will benefit most from NexSat products based on GOES and NWP data. The high-resolution polar-orbiting imagery, while still very useful when available, is well suited to support scientific field programs and basic research of various observed phenomena. For example, NexSat supported forecasters and flight planners during the NASA Tropical Cloud System Processes (TCSP) field program, conducted in the summer of 2005. The extensive online archive of imagery allows users to search for case studies of interest, and the collection of coregistered products provides an enhanced meteorological context.

Research algorithms are included on NexSat only after considerable offline testing of algorithm performance under a large range of conditions. However, automated product generation occasionally reveals flaws in algorithm design that must be addressed in an iterative mode. In this capacity NexSat is useful to U.S. Navy scientists as a tool for transitioning a robust product suite into the NPOESS era.

Whether the pursuit is research, weather monitoring, or education, NRL encourages all users to provide feedback on the utility of NexSat for their applications, as well as suggestions for improving the interface/content, when leveraging these products for their various activities. It should be understood that all NexSat demonstration applications fall under the general disclaimer of "research and development." The inherent risks of any operational applications (e.g., decision making) based on the availability or fidelity of near-real-time NexSat demonstration products must therefore necessarily be assumed by the user. Despite best efforts to maintain the automated processing system, NRL is not under operational mandate, and occasional data dropouts (e.g., hardware failures and temporary network outages) may occur.

CONCLUSIONS. A move toward the operational exploitation of next-generation optical-spectrum radiometers [research sensors; e.g., MODIS, Sea-viewing Wide Field-of-View Sensor (SeaWiFS)] began in 2002 with support of military assets in the Middle East. However, access to the Satellite Focus resource was restricted exclusively to the DoD. This paper introduces NexSat as the pubic analog to Satellite Focus. Featuring a broad collection of environmental products based on contemporary operational and research-grade sensors, NexSat illustrates a subset of the capabilities anticipated from NPOESS (with an emphasis placed on VIIRS applications).

In the context of visualizing the current weather situation, NexSat seeks to inform, educate, and capture the interest of a broad audience that includes the government, academia, private/public users, and potential future scientists. From the DoD-specific perspective, NexSat forms a bridge between DMSP/POES/MODIS and the NPOESS Preparatory Project (NPP) in the short term. In the long term, it represents a formal transition path toward achieving readiness for NPOESS-era sensor technologies.

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